Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **12**, No. 3, pp. 797-814

DOI: 10.4208/aamm.OA-2019-0055
June 2020

Vibration Control for Flexible Spacecraft using Multi Impulse Robust Input Shaper and Optimal Control Method

Yanfeng Du*, Cong Wang, Yan Zhou and Juncheng Lu

School of Astronautics, Harbin Institute of Technology, Harbin 150001, Heilongjiang, China

Received 27 February 2019; Accepted (in revised version) 19 June 2019

Abstract. Lightweight and flexible structures are often used in the engineering field which may produce the long time residual vibration of flexible appendages. In order to reduce the residual vibration of the flexible manipulator, a control method of combining the multi-impulse robust shaper with the linear quadratic regulator controller is put forward in this paper. The Lagrange equation and assumed mode method are used to obtain the dynamic equation of the manipulator. Then the dynamic equation is rewritten in state space, and the state equation of the closed-loop system is obtained after the optimal control is used. The multi-impulse robust shaper is designed according to the system frequency and damping ratio and is used to shape the required angle. The input torque is obtained by the linear quadratic regulator controller. The proposed combination controller is compared with the combination controller of ZVD shaper and the optimal control method, the combination controller of the EI shaper and the optimal control method, and optimal controller. The robustness of the proposed controller is then investigated. The simulation results show that the proposed combination controller has a better advantage in suppressing residual vibration than other controllers and has a good performance in the robustness of natural frequency.

AMS subject classifications: 65C20, 65M12, 70J50, 70Q05, 74H45

Key words: Flexible manipulator, combination controller, multi-impulse robust shaper, optimal control method, residual vibration suppression.

1 Introduction

Lightweight and flexible structures such as solar array, deployable truss antenna and large spatial manipulator are often employed for the spacecraft with the development of aerospace industrial engineering. The flexible structures have many advantages over the

*Corresponding author.
Email: duyanfeng_hit@163.com (Y. F. Du)

rigid ones for spacecraft. For instance, the flexible structures can maneuver quickly, consume less energy, and carry bigger task targets due to the lightweight property. However, the residual vibration after the spacecraft carries out the maneuvering task is produced because of the spacecraft structure flexibility which may influence the pointing accuracy and the structure safety. For high resolution remote sensing and laser communication satellite, the residual vibration degrades the performance of these satellites seriously.

In order to avoid or minimum the weakness of flexible structures, the residual vibration of flexible structures should be controlled. The predominant objective of the residual vibration control is to reduce and suppress residual vibration of spacecraft appendages after maneuvering. The flexible manipulator vibration characteristic can be obtained when the dynamic model is established. Therefore, it is necessary to develop an accurate dynamic model of the flexible spacecraft for the sake of control the flexible structures effectively. There are many approaches to model the flexible structures dynamic equations. Li et al. [1] established the dynamic model of the rotating hub-functionally graded material beam system by rigid flexible coupled dynamic theory, assumed modes method and Lagrange's equations. The dynamic stiffening effects are captured using their developed dynamic model. Then they [2] investigated the vibration features of the rotating functionally graded rectangular plates with the dynamic model established by Lagrange's equations. Zhao et al. [3] obtained the governing equation of the hub-beam system by Newton's law and the interaction of the beam's elastic motion and hub's motion is taken into consideration. The nonlinear partial differential equation is derived and reduced to an infinite system of a nonlinear ordinary differential equation in the spatial domain through Fourier's series expansion. And then the dynamic characteristic of the hub-beam system is obtained in their study. Pratiher et al. [4] developed the motion equation of a single link flexible visco-elastic Cartesian manipulator based on the D' Alembert principle and generalized Galarkin method. And the manipulator vibration is suppressed due to visco-elastic features in their research. Meng et al. [5] obtained the dynamic equations of the space robot system with flexible appendages and analyzed the dynamic coupling characteristics. Invernizzi et al. [6] established motion equations of the rotating slender beams through geometrically exact approach. Gasbarri et al. [7] derived the dynamic equation of an orbiting flexible satellite through classical Larangian approach and standard Finite Element tool. They [8] took the spacecraft flexible appendages into consideration when modelling the dynamic equations of spacecraft with the fuel slosh. Bouzgarrou et al. [9] derived the dynamic equation of flexible manipulators using Lagrange's approach and investigated the dynamic characteristics. Wei et al. [10] analyzed the flexible-link flexible-joint manipulator dynamic characteristics by the global mode method. They compared the simulation results with other researchers' numerical results derived by the assumed mode method and finite element method and a satisfied agreement is obtained. Different model methods have different advantages. The flexible manipulator dynamic model obtained by assumed mode method can be easily used for controller design. Thus, the Lagrange's equation of motion and the assumed modes method is used in this paper.

After the dynamic model of the flexible spacecraft is obtained, the vibration control